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IRRIGATION AND DRAINAGE DIVISION

Proceedings of the American Society of Civil Engineers

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Paper
(Discussion open until June 1, 1956)

JOURNAL

IRRIGATION AND DRAINAGE DIVISION

Proceedings of the American Society of Civil Engineers

METHODS OF DETERMINING CONSUMPTIVE USE OF WATER IN IRRIGATION[1]

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(Proc. Paper 884)

SYNOPSIS

Attention is first called to some of the early investigations of the "duty of water" in irrigation. As knowledge was acquired in this field of research, attention became focused on the "consumptive use of water" or "evapo-transpiration." Standard methods of determination of rates of consumptive use are then very briefly described and the utilization of results thus obtained to measure farm and valley uses are then described.

INTRODUCTION

Investigations concerning the consumptive use of water by crops grown on irrigated farms have been carried on by State and Federal agencies for well over fifty years. Due to the constantly increasing value of the water used and of the crops produced, such investigations should, and no doubt will, continue indefinitely in order to increase irrigation efficiencies with improved methods and procedures.

The early studies in this field of research had to do with the "Duty of Water" on irrigated farms and projects by such authorities as Dr. Elwood Mead, while he was in charge of Irrigation Investigations for the U. S. Department of Agriculture and Dr. John A. Widtsoe, formerly president of Utah Agriculture College. In his early practice in irrigation engineering, the speaker made considerable use of reports by Don H. Bark on cooperative investigations in Idaho, to name only three experts in this field in the early 1900's.

Many other contributions to our knowledge of the duty and consumptive use of water, such as descriptions of original research and experimentation or explanations and discussions of the work of others, are to be found in standard text and reference books, several titles being given in the Appendix.(4,5,6,7,8)[3]

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1. Paper presented on September 8, 1955 at the Irrigation and Drainage Conference, A.S.C.E., at Denver, Colo.
2. Chf. Engr., Upper Colorado River Comm., Grand Junction, Colo.
3. Figures in parentheses refer to the references listed in the appendix.

Then, too, there are numerous papers and discussions to be found in the Proceedings Separates and Transactions of the American Society of Civil Engineers.[9, 10, 11 a, b, c, d, e] All of these and several other sources including bulletins of the Department of Agriculture[12, 13, 14, 15, 16, 17] have been drawn upon liberally and due credit is intended to be given here to each and all.

This paper, therefore, is in the nature of a review and summary of the work of others, with those books and reports of papers the writer happened to be more or less familiar and which were available for reference.

Definitions

The term "Duty of Water" refers to the relation of the area of land that is served by a given quantity of water.

S. T. Harding (M. ASCE) has called attention to the fact that a high duty of water goes with a small amount used, while a low duty indicates a large use of water.[5] He tries to avoid the confusion which often arises from such use of terms by substituting the expression "Water Requirement" as applying to the number of acre feet of water necessary to maintain a given crop per acre of land irrigated. This expression is clear but its use has been largely superceeded by the term "Consumptive Use of Water," which appears to have been introduced by John E. Field (M. ASCE) while State Engineer of Colorado.

Consumptive Use may be defined [11a, 12, 13] as:

> "The sum of the volumes of water used by the vegetative growth of a given area in transpiration and building of plant tissue and that evaporated from adjacent soil, snow, or intercepted precipitation on the area in any specified time, divided by the given area."[11a]

It is usually expressed in units of acre feet per acre per year (sometimes per month) for the locality and crop or vegetation or area considered. It is measured in various ways, such as by lysimeters or tanks, on experimental plots, in selected fields, on a whole farm, an irrigation project or the farms and projects in a river valley. Its determination for the entire drainage basin of a river system, for example, that of the Upper Colorado River, is required by the terms of the Upper Colorado River Basin Compact.

It should be obvious that consumptive uses will vary for different crops and that for any given crop the use will vary from year to year and from one locality to another, with the length of the growing season, the average temperature, the precipitation and the humidity. Besides these climatic factors, there are numerous others which are important also, such as the character, condition and treatment of the soil, and the practice of the irrigator in applying the water. Since the foregoing definition includes water evaporated from the soil surrounding the plants which constitute the crop, or other vegetation, as well as that used and transpired by the plants themselves, the term "evapotranspiration" is here considered as synonymous with the term "consumptive use."

Several methods have been used to measure consumptive uses of water by crops and by native vegetation. Among the most useful of these are: soil moisture, lysimeter, tank, and field plot experiments; ground water fluctuations, evaporation pan records, the integration method, inflow-outflow

measurements, effective heat and the correlation of water use with climatological data. Some of these measurements depend upon the use of results obtained in previous work and only a brief description of any methods can be given within the limits of this review. For more detailed information, one may consult references listed in the short bibliography in the appendix.

Soil Moisture Determinations

The method of applying soil moisture determinations to the measurement of evapo-transpiration is best adapted to experiments where the total amount of water made available to the plants or crops used in the investigation can be measured either as natural precipitation or as water artificially applied for irrigation. If there is a water table at a measurable distance below the surface, it should be at such depth below the root zone that the plants can not obtain water from the capillary fringe, but will use only that applied at the surface. Hence, if very heavy rains are likely to occur so that deep seepage will result after a storm or if an excessive amount of water is applied in irrigation, the amount of such seepage must be measured or estimated and proper corrections made. In localities where practically no precipitation occurs during the growing season, this method is well adapted to obtain reliable measurements of consumptive use. Soil samples are usually taken before and after each irrigation and the moisture content determined by standard laboratory procedure. One advantage of this method is that it can be used on experimental plots of any practical size and the plots can be selected so as to be surrounded by similar crops or vegetation. The experiments should then reflect the consumptive use of water under the most natural conditions for accurate results.[6, 9, 11a, 15, 17]

Tank or Lysimeter Experiments

When lysimeters were first used in experiments to determine the consumptive use of water, the results obtained were qualitative rather than quantative by present standards. Early experimenters did not always give full details as to the conditions or procedures used so that their results could not always be properly compared. Tanks of the largest practical size should be used and they should be placed so as to be surrounded by natural conditions as to local crops and vegetation, undisturbed soil, water table, etc. Accurate observations and records should be secured as to effective precipitation, time, amount and frequency and method of irrigation, water lost by deep seepage if any, and the height and movement of ground water if the presence of such water is made a part of the program of experiments. The most accurate method of determining evapo-transpiration when this method is used, is of course by weighing,[6, 11a, 15] but with the largest tanks this is not always practical. In some experiments by Ralph L. Parshall (M. ASCE) to determine the rates of evaporation from saturated soils and river sands, Mariotte tanks were used successfully to control water table elevations.[16]

Ground Water Fluctuations

Where a considerable area of irrigated land is relatively flat and when there is an adequate water supply, it is sometimes possible to estimate the average consumptive use of water for the area by an analysis of the fluctuations in the elevation of the ground water table. After irrigation practice has become well established, the ground water table is usually somewhat higher than formerly. If there is a continuous inflow of underground water into the area and if capillary water is within reach of the root zone of the crops, recorders may be set at observation wells so as to obtain continuous records of the variations in the level of the water. Then, by making the necessary allowances for irrigation water and precipitation and knowing the specific yield of the soil, it is possible to estimate the consumptive use for the area.(6, 9) This method has been used with very satisfactory results in Arizona, California and Utah.(11a)

Evaporation Pan Records

Occasionally, one may need to estimate the losses of water from swamps or other low areas having vegetation known to be heavy users of water (phreatophytes). If evaporation pans are installed at such places, it may be possible to utilize the evaporation data obtained to estimate evapo-transpiration in the area. It is necessary here, as it is with all other methods, to take proper account of precipitation and irrigation water if either reaches the area, and a factor depending on judgment or experience would also have to be applied to the observations. However, helpful information may be obtained for comparison with other data from similar areas.(6)

Integration Method

Consumptive use determinations for a variety of crops and native vegetation made by the above or other methods are required when the integration method is used to obtain the consumptive use of water on a farm or irrigation project. In certain cases, this method has been used with satisfactory results to obtain project and even valley rates of consumptive uses.

To apply this method in a valley for example, having previously secured the rates of consumptive use for the various crops, one must obtain the acreage of each crop and of the pastures and incidental areas, together with the total area of each classification of the land use in the valley. Then the sum of the products of the total area of each type of crop or other class of land by its average rate of consumptive use will give the total consumptive use or stream depletion in the valley. This total depletion quantity divided by the total area then gives the weighted average rate of consumptive use.(9, 10, 11a, 14, 15) The above outline of the integration method may be an over simplification of the procedure.

When applied by different individuals on different irrigation projects, the results may not always be properly compared. In a given valley there may be several irrigation projects but annual records of the areas under cultivation may not be kept on exactly the same basis. The average in one case may be based on the acreage of the actual crops to the exclusion of such areas as are

occupied by houses, barns, corrals, ditches, roads, etc., giving the evapotranspiration rate for the net area cultivated. On another project, the total amount of depletion computed may be divided by the total area of the project, thus giving a smaller rate of use when based on this gross area.

In other words, it is very desirable that the fullest explanation be made of all details in reporting results so that they can be used to check and compare with data obtained by other methods or in other areas. For the purpose of comparison, results by the integration method have been of special value in connection with investigations in the Upper Colorado River Basin.[13, 14]

Inflow-outflow Method

In theory the inflow-outflow method as applied to the determination of valley consumptive use requires the actual measurement of all water entering the area. This should include both surface and subsurface inflow and precipitation, especially that falling on the valley floor, and also quantitative data as to any material changes in the amount of storage in the ground water reservoir in the area. Then the difference between the inflow and the outflow, both surface and subsurface plus the algebraic difference between ground storage at the beginning and at the end of the period is the consumptive use in the given area.

In mathematical terms this can be shown by the following equation:

$$U = (I + R) + (G_s - G_e) - Q$$

where:

U = the consumptive use for the period selected, usually 12 months.
I = the inflow during the period.
R = the effective rainfall on the valley floor for the period.
Q = the quantity of outflow for the period.
G_s and G_e are the volumes of water in ground storage at the beginning and end of the period.

All quantities are to be given in acre feet. Harry F. Blaney, (M. ASCE), notes that any change in the amount of capillary water will be so small that it can be neglected.[11a, 15]

The inflow-outflow method or some modification of it has been used by numerous engineers, among them may be mentioned Blaney, Criddle, Erickson, Harding, Hart, Lee, Lowry, Johnson, Morin and Tipton. In recent years it has been adopted for use in connection with the negotiation and administration of several Interstate River Compacts, one of which is the Upper Colorado River Compact of 1948. Typical results by the use of this method are shown in Table 1 of the Appendix copied by permission from Table 5 of the paper on the Consumptive Use of Water, by Harry F. Blaney, (M. ASCE).[11a, 15]

Correlation Methods

The correlation of consumptive uses of water with certain climatological factors has been successfully developed by several investigators. Charles R. Hedke, M. ASCE, appears to have been one of the first to use the "effective heat" (or number of day-degrees) available to agricultural crops during the

growing season or crop year. No attempt will be made here to discuss Hedke's method, but only to record that he used it as early as 1916, during investigation in the Poudre River and San Luis Valleys in Colorado and in the Rio Grande Valley in New Mexico, with "gratifying results."(9)

The many years of constant research carried on with a somewhat similar approach to this problem by Harry F. Blaney, (M. ASCE), have resulted in a very useful and reliable method which has many applications. Results by his method have been checked by other methods in several instances with very satisfactory agreement. Your speaker is more familiar with this method than with any other since Blaney and Criddle made a report on "The Consumptive Uses of Water Rates in the Upper Colorado River Basin" for the Upper Colorado River Compact Commission in the summer of 1948. It was his privilege to be one of the engineers in the party that accompanied Mr. Blaney and Mr. Criddle during the time they were in the field collecting the final data to complete their report to the Compact Commission. Quoting from this report:

> "Briefly, the procedure is to correlate existing consumptive use data with mean monthly temperatures, percent of daytime hours and precipitation for the frost free period or irrigation season and for the entire year. The coefficients so developed for different crops are used to transfer consumptive use data from one section to other areas where only climatological data are available."

This method was more fully described by Harry F. Blaney and Wayne D. Criddle in a report of the Division of Irrigation, of the Soil Conservation Service, U.S.D.A., entitled "Consumptive Use of Water Rates in the Irrigated Areas of the Upper Colorado River Basin" dated April, 1949.(13) The procedure can best be described in their words.

> "Neglecting the unmeasured factors, consumptive use varies with the temperature and the daytime hours, and irrigation requirement is also dependent on precipitation. By multiplying the mean monthly temperature (t) by the monthly percent of daytime hours of the year (p), there is obtained a monthly consumptive use factor (f). It is then assumed that the consumptive use varies directly as this factor or, expressed mathematically, $U = KF$
>
> where: U = Consumptive use of crop in inches for any period.
> F = Sum of the monthly consumptive use factors for the period (sum of the products of mean monthly temperature and monthly per cent of annual daylight hours ($t \times p$).
> K = An empirical coefficient.
> t = Mean monthly temperature in degrees Fahrenheit.
> p = Monthly per cent of daytime hours of the year.
> $f = t \times p$ = Monthly consumptive use factor.
>
> "By knowing the consumptive requirement of water by a particular crop in some locality an estimate of the use by the same crop in some other areas may be made by application of the formula. Table 1 gives a summary of the consumptive use of water (U) by alfalfa and cotton in various localities in the West as determined by investigators, together with the calculated consumptive use factor (F) and the crop coefficients (K) in the areas studied. In planning to supply the irrigation requirements of any new

project it then becomes necessary to estimate the acreage to be planted to each crop, determine the unit use of water by each crop based on known use in other areas and add the products for all the crops. This calculation will indicate the total consumptive use for the project.[4] Allowance must, of course, be made for the use by native vegetation, water surface, evaporation and other minor uses.

"Assumptions: In order to apply the results of any study in one area to some other area, it is usually necessary to make certain minor assumptions. If sufficient basic information is available, some of the assumptions may be replaced by actual data, but rarely are all the data known in sufficient detail for reliable use. In other words, the more data available, the more accurate the estimates or assumptions, but some doubts still exist. For practical use the following assumptions must be made in applying the consumptive use formula between areas:

1. The fertility and producing power of the soils are similar.
2. Sufficient water is applied and at the proper time to maintain good growing conditions.
3. The length of growing season, to a large extent, determines the production and annual consumptive use of continuous growing crops such as alfalfa and pasture.
4. Consumptive use of water varies directly with the consumptive use factor."

The Blaney-Criddle method has certain advantages since the percentage of daylight hours in any month for various latitudes are given in published tables.[11a] With these quantities taken for the months and fractions during the growing season and the mean monthly temperatures from Weather Bureau Reports consumptive use factors can be computed for almost any crop in any western location since reliable records of experimental determinations of rates of consumptive uses for many crops and vegetative types are also available. The necessary coefficient (K) can therefore be computed as the ratio of each observed value of consumptive use (U) by its corresponding factor (F). Typical rates of consumptive use for various crops are given in Tables 2 and 3 in the Appendix.[15]

It is assumed by Blaney and Criddle, as stated above in assumption 4, that consumptive use rates vary directly with the consumptive use factor. The data on alfalfa given in Table 2 of the Appendix was used to test the validity of this assumption, by computing the mean (M), standard variation (SV) and the coefficient of variation (CV), for each of the three quantities, consumptive use (U), consumptive use factor (F), and the crop coefficient (K). The seven records shown in the table are of experiments made in seven different states with consumptive uses varying from less than 20 acre-inches per acre in California to more than 40 acre-inches for one year in Texas. Yet the coefficients of variation (CV) of the consumptive uses (U) and of the consumptive use factor (F) are respectively 34.5 % and 30.0 %. That these two quantities are directly proportional for all practical purposes is also shown by the further fact that the crop coefficient (K) has a variation indicated by its coefficient of 11.1 %. This shows extremely high correlation between consumptive use for this crop and the index of the heat available during the growing period. Once the coefficient (K) has been determined for any crop or type of vegetation,

its use with reasonable judgment is certainly justified on other areas. In the appendix, there are given values of (K) suggested by Blaney for a number of the common crops grown by irrigation in Western United States. These two tables are taken by permission from the paper by Mr. Blaney on "Evapo-Transpiration in Western United States."(15) In using consumptive-use coefficients given in Table 3, one should note that the lower values of (K) are for areas along the coast while the higher values are for more arid climates.

Native Vegetation and Municipal Areas

Some of the methods that have already been mentioned are available for the determination of evapo-transpiration rates from incidental areas such as natural grass land and pasture and also for large plants or shrubs, orchards and wooded areas. Consumptive use rates for these areas are contained in several of the references listed in the appendix.(13, 14, 15, 18) In addition an excellent report on the "Consumptive Use of Water by Forest and Range Vegetation" by L. R. Rich, Hydrologist with the Southwestern Forest and Range Experiment Station at Tuscson, Arizona, is available as one section of the Symposium in the ASCE Transactions for 1952, Vol. 117.(11b)

Municipal areas are often considered as taking approximately the same evapo-transpiration rates per acre as the surrounding cultivated, or native vegetation. Another section of the above mentioned Symposium is devoted to rather detailed, and hence very valuable report, on the investigations on the "Consumptive Use in Municipal and Industrial Areas,""to determine a fair distribution of water rights in the Raymond Basin Area, of Pasadena, Calif.", by George B. Gleanon, (Assoc. M. ASCE).(11d) The limited scope of this paper precludes discussion of these papers which, however, should be called to the attention of those who may be interested.

Discussion

The Upper Colorado River Commission was organized under authority of the Upper Colorado River Basin Compact of 1948. There are five Commissioners, one each from the four states of Colorado, New Mexico, Utah and Wyoming, with the chairman appointed by the President of the United States. The Commission is empowered, among other things, to make findings as to the consumptive use, or more specifically, the man-made stream depletion in each of these states and in the Upper Basin as a whole each year "by the inflow-outflow method." Hence the engineering department of this Commission has spent much time and effort in the study of methods for the determination of the consumptive use of water in irrigation and of how best to apply appropriate methods in the determination of man-made depletions of stream flow in the Upper Basin of this very important river.

The area of the Upper Colorado River Basin is about 110,000 square miles or 70,400,000 acres. This is 70 million acres more than the area of the San Luis Valley of Colorado which is the largest area reported by Blaney and Rohwer as having determined valley consumptive uses by the inflow-outflow method.(15) The irrigated area in this basin, however, is something on the order of 3% of the total and it is divided into numerous sub-basins, both large and small, separated by long, deep and magnificent canyons on tributaries as

well as on the main stem of the river. There are nearly 300 streams of varying size upon which about twice that number of gaging stations have been operated by the U. S. Geological Survey for periods varying from only two or three years up to as many as fifty years. This does not include the very large number of streams from which many ditches take water but on which the U. S. Geological Survey has never installed a gaging station. Recently it has been estimated that there are between 15,000 and 20,000 canals and ditches diverting water for use on an equivalent area of the order of 2,000,000 acres in this basin. This may give a little idea of the magnitude of the task undertaken in these studies. With only two or three ground water observation wells in the Upper Colorado Basin, information on this source of inflow and storage is difficult to obtain to say the least. The records of annual discharge of the Colorado River at Lees Ferry, which is near the outflow point of the Upper Basin, are good since 1922 when the recording gage was installed. But with a limited number of rim stations, most of which have much shorter periods of continuous operation, it has only been possible to use indirect methods to obtain data which can be used in applying the inflow-outflow method in the valleys of this river system. The attack on this problem has therefore been to develop inflow indexes which are used with pertinent climatological factors in multiple correlation relationships. These studies are not complete and in fact they may continue indefinitely as additional years of records become available and new facts are learned which tend to increase the accuracy of such inflow-outflow relationships as are being developed. Several problems are still to be investigated and questions continue to arise which will require answers as the investigation continues.

Because interest in this problem, among others before the Upper Colorado River Commission, seems to be rather widespread, this review of some of the methods of determining the consumptive uses of water in the West and of the rather special conditions governing the application of the inflow-outflow method to the measurement of man-made stream depletions on a basin-wide basis is offered for your information at this time.

CONCLUSION

Up to the present time, the Upper Colorado River Commission has not adopted any regulation or procedure by which to "make findings of fact" as to the amounts of man-made depletions either at Lee Ferry or at State Lines. Progress Reports are made from time to time (this paper may be considered in that category) which are reviewed by the committee of engineering advisors to the Commission. When this committee makes recommendations to the Commission which can be adopted for the application of the inflow-outflow method to its purposes, it is hoped that it will also authorize a technical paper on that subject.

APPENDIX

METHODS OF DETERMINING CONSUMPTIVE USE OF WATER IN IRRIGATION

REFERENCES

1. The Use of Water in Irrigation, by Elwood Mead, with Computations of Records, etc. by C. T. Johnston (Reprint Bulletin 86, USDA). Annual Report of Irrigation and Drainage Investigation, 1904.

2. The Production of Dry Matter with Different Quantities of Irrigation Water by John A. Widtsoe, Utah College of Agriculture, Experiment Station Bulletin 116, 1912.

3. Experiments on the Economical Use of Irrigation Water in Idaho by Don H. Bark, U.S.D.A., Bulletin 339, April, 1916. Also a more detailed report by the State Engineer of Idaho of the same experiments, the State cooperating with the U. S. Department of Agriculture.

4. Irrigation Engineering, Ch. X, Duty of Water, by Davis and Wilson, 7th Ed.

5. Irrigation Practice and Engineering by Etcheverry and Harding, Vol. I, 2nd Ed., Chs. IV and V, 1933.

6. Hydrology Handbook, ASCE, Manual of Engineering Practice, No. 28, Evapo-Transpiration or Consumptive, Ch. 4, Art. 10, page 136.

7. Irrigation Principles and Practice, by O. W. Israelsen, 1st Ed. Ch. XIV, 1932.

8. Hydrology, Physics of the Earth—IX, Edited by Oscar E. Meinzer, Ch. VIII by Charles H. Lee, 1st Ed. 1949.

9. Consumptive Use of Water in Irrigation. Progress Report of the Duty of Water Committee. Trans. ASCE. Vol. 94 (1930) 1340.

10. Consumptive Use of Water for Agriculture by Robert L. Lowry and Arthur F. Johnson. Trans. ASCE. Vol. 107 (1942) 1243.

11. Consumptive Use of Water, A Symposium, by Harry F. Blaney and others. Trans. ASCE. Vol. 117 (1952)
    a) Consumptive Use of Water by Harry F. Blaney, page 949.
    b) Consumptive Use of Water by Forest and Range Vegetation by L. R. Rich, page 974.
    c) Consumptive Use of Water on Irrigated Lands by Wayne D. Criddle, page 991.
    d) Consumptive Use in Municipal and Industrial Areas, by George B. Gleason, page 1004.
    e) Consumptive Use in the Rio Grande Basin, by Robert S. Lowry, page 1014.

12. A Method of Estimating Water Requirements in Irrigated Areas from Climatological Data by Harry F. Blaney and Wayne D. Criddle, U.S.D.A., S.C.S. Dec. 1947. (Mimeographed Report)

13. Consumptive Use of Water Rates in the Upper Colorado River Basin by Harry F. Blaney and Wayne D. Criddle, U.S.D.A., S.C.S. April, 1949.

14. Consumptive Water Use and Requirements in the Colorado River Area of Utah, by Willis C. Barrett and Cleve H. Milligan, Special Report No. 8, Utah State Agricultural College Experiment Station, S.C.S., U.S.D.A., and State Engineer of Utah, March, 1953.

15. Evapo-Transpiration Measurements in Western United States, by Harry F. Blaney. Paper given at the Tenth General Assembly of the International Union of Geodesy and Geophysics at Rome, Italy, September, 1954.

16. Experiments to determine Rate of Evaporation from Saturated Soils and Riverbed Sands, by Ralph L. Parshall, Trans. ASCE. Vol. 94 (1930) 961.

17. Irrigation Requirements of California Crops, Bulletin No. 51, November 1945. Department of Public Works, Division of Water Resources, State of California.

18. Consumptive Use Requirements for Water, by Harry F. Blaney, Agricultural Engineering, Vol. 35, December, 1954.

APPENDIX

TABLE 1. - Examples of Valley Consumptive Use of Water Determinations by Inflow-Outflow Method

Location	Year	Area (acres)	ANNUAL CONSUMPTIVE USE Total (acre-feet)	Average (feet)	Authority
San Luis Valley, Colo.	1925-1935	400,000	664,900	1.66	Blaney-Rohwer
San Luis Valley, Colo.	1936	400,000	685,423	1.71	Blaney-Rohwer
San Luis Valley, Colo.	1930-1932	17,300	26,215	1.52	Tipton-Hart
Isleta-Belen, N. Mex.	1936	17,500	38,700	2.28	Blaney-Morin
Mesilla Valley, N.Mex.	1919-1935	109,000	297,756	2.73	Blaney-Israelsen
Mesilla Valley, N.Mex.	1936	110,418	303,683	2.75	Blaney-Israelsen
Carlsbad, N. Mex.	1921-1939	51,700	129,752	2.51	Blaney-Morin-Criddle
Carlsbad, N. Mex.	1940	51,700	119,898	2.33	Blaney-Morin-Criddle
New Fork, Wyo.	1939-1940	25,000	....	1.59	Lowry-Johnson
Michigan-Ill.-Colo.	1938-1940	43,000	....	1.50	Lowry-Johnson
Uncompahgre, Colo.	1938-1940	137,700	....	2.28	Lowry-Johnson

TABLE 2. - Examples of Coefficients (K) for Irrigated Crops Developed From Measurements of Consumptive Use and Climatological Data*

Location and crop	Year	Growing Season or Period	Consumptive Use Rate (U)	Factor (F)	Coefficient (K)[1]
		Dates	Inches		
ALFALFA					
Carlsbad, N. Mex.	1940	4/18-11/10	38.6	43.59	0.88
Fort Stockton, Tex.	1940	4/13-11/11	40.5	46.28	.88
San Fernando, Calif.	1939	5/26-9/9	19.3	23.35	.83
Ferron, Utah	1948	5/9-10/6	24.2	30.23	.84
Mesa, Ariz.	1948	2/10-12/3	52.5	57.51	.91
Ontario, Ore.	1941-42	5/1-10/5	29.4	35.50	.83
Gooding, Idaho		5/23-9/24	21.6	26.18	.83

Table 2 - Cont'd.

Location and crop	Year	Growing Season or Period	Consumptive Use Rate (U)	Consumptive Use Factor (F)	Consumptive Use Coefficient (K)[1]
		Dates	Inches		
COTTON					
Mesa, Ariz.	1935	4/1-10/31	30.9	49.08	.63
Bakersfield, Calif.	1927-30	4/1-10/31	29.2	47.14	.62
Carlsbad, N. Mex.	Normal	3/28-11/3	28.7	47.39	.61
Fort Stockton, Tex	1940	4/13-11/11	28,9	46.28	.62
SMALL GRAINS					
Scottsbluff, Nebr.	1932-35	4/20-7/25	14.72	20.02	.74
Prosser, Wash.	1944	3/20-7/16	18.00	23.32	.77
Ferron, Utah	1948	5/13-8/21	17.8	20.86	.85
Davis, Calif.		3/1- 6/7	12.0	17.73	.68
ORCHARD - ORANGES					
Mesa, Ariz.	1931-34	3/1-10/31	32.4	58.26	.56
Azusa, Calif.	1929	4/1-10/31	21.8	43.19	.50
San Fernando, Calif.	1940	4/1-10/31	22.1	43.73	.51
ORCHARD - DECIDUOUS					
Ontario, Calif.	1928	4/1-9/30	28.4	37.73	.75
Wenatchee, Wash.	1908	4/15-10/22	23.0	38.15	.60
Albuquerque, N. Mex.	1936	5/1-9/31	19.5	33.94	.58
PASTURE					
Vernal, Utah	1948	5/17-10/6	25.0	27.42	.91
Murrietta, Calif.	1953	4/1-10/31	35.04	42.04	.84
POTATOES					
Bonners Ferry, Idaho	1947	5/8-9/27	22.95	29.35	.78
Utah County, Utah	1938	5/15-9/15	22.50	27.23	.83
Prosser, Wash.	1945	4/20-8/4	16.65	22.81	.73
Davis, Calif.		3/1-6/30	16.8	22.93	.73
Logan, Utah	1902-29	5/20-9/15	15.0	25.27	.60
VEGETABLES					
Stockton, Calif.	1925-28	5/1-9/30	21.4	33.91	.63
Stockton, Calif.	1925-28	4/1-10/31	24.6	44.18	.56

[1] $K = \frac{U}{F} = \frac{\text{Consumptive use}}{\text{Use factor}}$ = Empirical coefficient

* Table 6 of "Evapo-Transpiration Measurements in Western United States" by Harry F. Blaney.

TABLE 3. - Consumptive-use Coefficients (K) for Irrigated Crops in Western United States*

Crop	Length of growing season or period	Consumptive-use Coefficient[1] (K)
Alfalfa	Between frosts	0.80 to 0.85
Beans	3 months	.60 to .70
Corn	4 months	.75 to .85
Cotton	7 months	.60 to .65
Flax	7 to 8 months	.80
Grains, small	3 months	.75 to .85
Grain sorghums	4 to 5 months	.70
Orchard, citrus	7 months	.50 to .65
Orchard, walnuts	Between frosts	.70
Orchard deciduous	Between frosts	.60 to .70
Pasture, grass	Between frosts	.75
Pasture, Ladino clover	Between frosts	.80 to .85
Potatoes	3½ months	.65 to .75
Rice	3 to 5 months	1.00 to 1.20
Sugar beets	6 months	.65 to .75
Tomatoes	4 months	.70
Vegetables - small	3 months	.60

[1] The lower values of (K) are for coastal areas, the higher values for areas with an arid climate.

*Table 7 of "Evapo-Transpiration Measurements in Western United States" by Harry F. Blaney.

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DISCUSSION

(Proc. Paper 922)

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Discussion of
"DIVERSION OF CANALS"

by Hassan M. Ismail
(Proc. Paper 461)

HASSAN M. ISMAIL,[1] A.M. ASCE.—Sir Claude Inglis and Mr. Harold Tults gave very helpful lists of Indian and German references for the studied subject.

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Discussion of
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(Proc. Paper 451)

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1 Assoc. Prof., Cairo Univ., Egypt.

Discussion of "WATER RIGHTS IN HUMID AREAS"

by Howard T. Critchlow (Proc. Paper 705)

H.E. THOMAS.[1]—The growing importance of the problem of water rights in humid areas is suggested by the table showing the extent of supplemental irrigation in the 31 Eastern States. The practice of supplemental irrigation has increased rapidly since 1950, when use for irrigation was negligible in 20 of those states, and only Arkansas, Florida, and Louisiana used water for irrigation in quantities comparable to some of the 17 Western States (Mac Kichan, 1951).

This rapid expansion of irrigated acreage in humid regions is continuing, at least in some states: in Mississippi the irrigated acreage in 1955 was 300,000 acres, 160,000 acres more than in 1954.

The term "supplemental" irrigation is indicative of the irrigation requirements in these humid regions: the purpose is to supplement the precipitation when necessary during the crop growing season. By contrast, irrigation is the basic method of providing water to crops in the arid regions of the 17 western states. Rainfall during the growing season ranges from nil in some parts of California, to 50 percent or more of the crop requirements in the High Plains of Texas and Kansas. It is generally true in arid regions, therefore, that surface-water and ground-water supplies provide the basic water requirements for crops each year; rainfall serves as a supplement, and is most welcome, but is never - well, hardly ever - adequate for maturing of crops.

As shown by Thornthwaite (1948), the 17 Western States embrace practically all of the areas of perennial water deficiency in the nation. By contrast, the 31 Eastern States constitute an area of perennial water surplus, because the average annual precipitation is more than enough to offset all evaporation from lakes, ponds, and land surfaces, plus all transpiration from native vegetation and croplands. The difference between the average precipitation and the evapotranspiration constitutes the water surplus, which is temporarily stored in lakes and ground-water reservoirs, and ultimately discharged by streams flowing to the oceans.

It would seem that the common-law doctrines as to water rights in humid regions represent an intuitive recognition by society that, over the long pull, there is enough water for all lands, with enough surplus to maintain sea-level in the face of continuing evaporation from the oceans. (The writer can find no authority to quote on this subject, however). The riparian doctrine permits each owner of land along a lake or watercourse to use the water at his pleasure, provided he does not diminish the quantity or impair the quality of the water in the lake or watercourse. Inasmuch as consumptive use necessarily diminishes the quantity and nonconsumptive use generally

1. Staff Geologist, Ground Water Branch, U.S. Geological Survey, Salt Lake City, Utah.

changes the quality of water, the riparian doctrine can be hydrologically sound only in an area of water surplus, for such surpluses can replace the consumptively-used water or dilute the non-consumptively used water. Legal doctrines developed for ground water in humid regions also presume an ample water supply, for they either permit unlimited use by the landowner of water from his wells, or they permit a reasonable use in accordance with similar rights of his neighbors (Thomas, 1955, p.2).

The water shortages in numerous localities in the East, the increasing competition among users for available supplies, and the doubts as to adequacy of existing water-rights law, do not indicate that the 31 Eastern states constitute an area of "perennial water surplus." A possible explanation for these difficulties is that the actual precipitation deviates greatly from the long-term average, and these variations are reflected in fluctuations in amount of soil moisture, ground-water storage, and stream flow. The "surpluses" computed on the basis of long-term average precipitation represent averages of floods and droughts, growing seasons and non-growing seasons, years of maximum precipitation and years of minimum precipitation. Without facilities for storing water during periods of abundance, and holding it for use in periods of deficient precipitation, the long-term average precipitation is a meaningless statistic to the water user.

So far as agricultural use of water is concerned, the people of the humid regions for centuries have relied upon the soil for the storage of water from precipitation until it could be used by the crops. Some soils serve this purpose better than others, and the climates of some localities are less erratic than others, but the vagaries of the weather have always constituted a major gamble in farming. In recent years there has been increasing recognition of the fact that greater crop yields can be assured by making a supply of water continuously available to the plant roots (Thornthwaite, 1947; Newsweek, 1949). Supplemental irrigation has therefore become increasingly popular, and it is likely to grow in importance throughout the East, subject in each locality of course to the availability of surface or ground-water supplies.

In view of the prospects for further increasing use of water for irrigation in the East, together with evidence of increasing demand for water by municipalities and industries, one may anticipate more critical conditions in many localities that are already short of water, and also an increase in the number of localities with inadequate water supply to meet the increased demand. In matters pertaining to areas of water deficiency, relatively new to most Eastern states, the experiences of the 17 Western states may be of great value, because those states have long wrestled with problems of water deficiency.

The appropriation doctrine, recognized to a greater or less extent by all 17 Western states, is based upon the principle that in a perennially water-deficient area there cannot be enough water for the needs of all landowners; rights to appropriate water for beneficial use are therefore based on the time of first use ("first in use is first in right") and may be forfeited after a specified period of nonuse; and the sum total of appropriative rights is necessarily limited by the quantity of available water resources. Thus landownership per se does not give a right to use of contiguous or underlying water. Several states have specifically repudiated the common-law doctrine relating water rights to landownership, and have declared all water to be public property. Two features concerning the development of the appropriation doctrine in the Western states are worthy of note, because of their

contrast with conditions prevailing in Eastern states. First, the doctrine is embodied in the constitutions of some states, and in some other states is specified in statutes that in effect recognize customs that antedated statehood. Thus in many areas there has never been any implication that water rights have been vested in landownership. Second, the ultimate sources of the appropriated water (i.e., the areas where precipitation occurred) have been predominantly public lands, and still are very largely in national parks, forests, reservations, or other public domain.

Several of the Western states recognize landownership as a basis for some water rights, and have reached a variety of solutions to the problem of adapting the limited water supplies to the needs of the landowners. The doctrine of correlative rights, proposed in California more than 50 years ago, allocates the available water in proportion to the land area held by each landowner, but it has the disadvantage that if the total water supply is inadequate for all landowners, the allocated water is likely to be inadequate for each. In a recent decision by the California Supreme Court concerning water rights in an overdrawn ground-water basin, mutual prescription by all users was declared to have occurred to the extent of a proportional part of the overdraft, and unused landownership rights were considered to have been completely prescripted and therefore ceased to exist. Thus the factor of time of development, which is basic in the appropriation doctrine, has become the basis in this decision for differentiating between landowners permitted to use and those not permitted to use the underlying water. The factor of time is also an important element in New Jersey's regulation of pumping from wells in designated "critical" areas of the state.

In working out equitable means of apportionment of water in the humid regions, one should not lose sight of the fact that the long-time average precipitation is more than enough to affect the return to the atmosphere by evapotranspiration. Because of this favorable water balance, it should generally be possible to overcome local water deficiencies by foresight and comprehensive planning of water development, rather than by restrictive statutes or court decisions which might hamper that development. The problem of assuring an adequate water supply for agriculture - that is, providing water during periods of deficient rainfall in the growing season - may be solved wherever there is adequate provision for storage of surplus waters from other seasons; this may require construction of surface reservoirs, development of ground-water reservoirs, and also artificial recharge of developed ground-water reservoirs.

The problem of assuring adequate water supplies for municipal or industrial use may be more complex because of the concentration of demand in small areas. For large users of water it is obviously necessary to reserve a land area of sufficient size to provide surpluses large enough for the demand, and also to develop storage facilities that will give the requisite sustained yield. New York City has followed this general pattern of water development as the municipal water demand increased, and has progressed from the Croton to the Catskill and most recently to the Upper Delaware River reservoirs.

REFERENCES

MacKichan, K. A., 1951, Estimated use of water in the United States - 1950: U. S. Geol. Survey Circular 115, 13 pp.

Newsweek, August 8, 1949, Invisible drought: p. 43.

Thomas, H. E., 1955, Water rights in areas of ground-water mining: U.S. Geol. Survey Circular 347, 16pp.

Thornthwaite, C. W., 1947, Climate and moisture conservation: Am. Assoc. Amer. Geographers, vol. 37, pp. 87-100.

Thornthwaite, C. W., 1947, An approach toward a rational classification of climate: Geog. Rev., vol. 38, pp. 55-94, pl. 1.

Thornthwaite, C. W., in press, Modification of rural microclimates, in "Man's role in changing the face of the earth": Univ. of Chicago Press, Chicago, Ill.

C. E. BUSBY.[1]—A few comments on Mr. Critchlow's informative paper may be pertinent at this time. Of the nine western states using the riparian doctrine, Oregon, Nebraska and Kansas have reduced its application largely to domestic or family uses (exempted under the appropriation statutes), California has limited the extent of riparian and other uses by constitutional provision, and Washington seems to have accomplished much the same thing by statute. Thus, the western states which have only partially resolved the basic differences in the common law and statutory systems are North and South Dakota, Oklahoma and Texas. Some of these states are considering possible changes. The western states have all moved steadily toward the prior appropriation system as more practical and suitable to their needs. Reservation or development of water supplies to meet future needs is receiving increased attention.

Improved water policies have been adopted in recent years in New Jersey, South Carolina, Mississippi, Virginia, Kentucky, Indiana, North Carolina and Illinois. But these policies vary considerably from state to state and most of them have not been implemented as yet. Thus, their value or effectiveness may not be known for some time. Several eastern states are presently making studies of the need for basic water legislation. In this connection, it would seem that the northern states have more favorable water supply conditions and this may foreshadow legislation with only limited control measures, such as in Wisconsin.

Of four states with the largest irrigated acreage in the east, Louisiana, Arkansas and Mississippi are within the area of major rainfall deficiency shown by Thornthwaite.[2] Physical factors point to these and adjacent southern states as having the greater present need for water rights legislation. Water shortages in certain localities of these states, such as in the Piedmont and similar sections, seem to be more acute owing to variations in stream flow during seasons of high demand and to lack of ground water or the unavailability for economic uses, as well as rainfall deficiency.

It might be possible to apply some type of appropriation system to flood water conservation and use in some of the southern states to serve both riparian and non-riparian lands. And to limit the use of normal base flows largely to riparian uses under a limited permit system for the immediate

1. Water Rights Specialist, Soil Conservation Service, Berkeley, Calif.
2. See Figure IV, p. 58, Monthly Review, May, 1955, Federal Reserve Bank of St. Louis.

future. Minimum flows might be sharply limited as to use to avoid complications in the fields of pollution and domestic use. Provision for reservation of surface water supplies to meet future needs would seem to be desirable in any eastern state.

PAUL H. BERG,[1] A.M. ASCE.—The author has presented a very worthwhile contribution in analyzing the water rights in humid areas. The lack of adequate laws to permit the establishment of water rights which fix priorities between appropriators will perhaps be one of the greatest deterrents to maximum development of irrigation in humid areas. Since almost all of the states in humid areas have long followed the riparian doctrine, it undoubtedly will be difficult to rework the state laws to accommodate the doctrine of appropriation.

At the present time, the water law of Kansas, which was passed in 1945, is being contested in the Federal courts under the 14th Amendment to the Constitution. The basis for the contest is the claim that the 1945 law abrogates certain common-law rights, and it is considered that this is taking property without due process. This is only one of the many problems that will confront those in the humid areas when the attempt to establish the doctrine of appropriation, whereby, as between appropriators, the "first in time is the first in right," is made.

The subject of water rights in humid areas is being studied by Federal and state agencies and by privately endowed foundations. It is hoped that through coordination of these studies, the states within the humid areas may benefit from the experience in the western states and thus avoid many of the pitfalls and mistakes made in the western states.

J. C. ALEXANDER.[2]—In the Governor's message to the 1955 session of the Missouri General Assembly, he requested that a commission be established and granted funds to make a thorough study of the water resources of the State and recommend the uses they should fulfill. The General Assembly did not act upon this recommendation of the Governor. However, the Senate passed a resolution and appointed five members of their body to make such a study. The Attorney General ruled this committee to be without legal authority to expend state funds because the resolution was not carried through the legal procedures required by our statutes. Therefore, nothing was done by this group and it is inactive.

A survey of irrigated land in Missouri lists 35,431 acres as being supplied irrigation water for the year 1954. This acreage excludes all truck crops and rice. The earlier irrigators were the truck growers and their acreages have reached rather large proportions. It is believed that the total acreage under irrigation for 1954 would be slightly in excess of 40,000 acres excluding rice production.

The source of water for irrigation as determined from the survey indicates that 63.5 per cent comes from surface supplies and the remaining 36.5 per cent is supplied from ground water. Eighty-four per cent of the water is applied by the sprinkler method.

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Irrigation was practiced on all of the important field crops which are grown in the State. In descending order of importance they are as follows: corn, pasture, hay, cotton, truck crops, soybeans, oats, and tobacco.

Many farmers state that they did not start irrigation soon enough or they should have applied more water. They do agree that their yields were increased by the practice.

Hay was supplied the greatest amount of water which ranged from 2 to 30 inches for an average of 9.1 inches, pasture 2 to 18 inches for an average of 7.1 inches, corn 1 to 12 inches for an average of 4.9 inches, cotton 1 to 12 inches for an average of 4.6 inches, and soybeans 1 to 8 inches for an average of 3.8 inches. The application of water to tobacco and oats did not vary greatly among irrigators and the tobacco averaged about 7.0 inches and oats 4.0 inches.

During the growing season of 1955 the need for artificially applied water was not great and many farmers did not operate their equipment. In most parts of the State, yields were normal or above. Although the need for irrigation in the State does not appear necessary in all years, there are scattered areas that will benefit most years.

Discussion of "GENERAL ASPECTS OF PLANNED GROUND WATER UTILIZATION"

by Robert O. Thomas
(Proc. Paper 706)

HAROLD E. THOMAS.[1]—Although this paper is based largely on California experience, it has broad applicability to ground-water problems in many other states. As an example, Mr. Thomas' section on "Operation of Underground Storage" is an inclusive and yet concise statement of the complexities involved in operating California's ground-water reservoirs for maximum benefit to the greatest number of people. But it is equally applicable to the broad, alluvium-filled, intermontane valleys of other Western States. With only slight modifications it is also applicable to the gravel-and-sand aquifers of the Great Plains, the Atlantic and Gulf Coastal Plains, and the glaciated parts of the country. And much of the section is basic to the operation of all ground-water reservoirs, large or small, in consolidated or unconsolidated rocks.

In the section on "Present Status of Development," Mr. Thomas presents a picture of "haphazard local" development—from drilling of the first wells, to interference by later users, and ultimately to overdevelopment—that applies also to many ground-water reservoirs in other states. However, California has gone farther than have most states in the creation of ground-water problems, and in the solution of some of them. This is to be expected in a State where the annual pumpage from wells is estimated to be 40 percent of the nation's total. Since California has only 5 percent of the nation's area and 8 percent of its population, it is obvious that it is far beyond the national average in development and use of ground water. And in assuming leadership in this field, California has inevitably pioneered many aspects of ground-water development, as well as regulation of that development. In many respects it can thus serve as an experimental laboratory for other states.

California has also served as an experimental laboratory for the development and application of legal doctrines pertaining to ground-water. Apparently it has tried them all. Mr. Thomas mentions the State's early adherence to the English doctrine of unlimited use, its development of the doctrine of correlative rights, the adherence in its State water code to the American doctrine of reasonable use, and the recently developed doctrine of mutual prescription. The doctrine of appropriation is also recognized in California, as it is to a greater or less extent in all Western States; it originated from customs of California's miner Forty-niners, and was accepted by the California Supreme Court as early as 1855. Finally, in spite of all these doctrines, or perhaps because of their diversity, there have been opportunities for unbridled competition for ground water, with the result that several basins have been overdeveloped. Specific instance of overdevelopment have been acclaimed as an economic good by numerous experts, on the ground

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that because of it California's largest cities were able to grow large enough and wealthy enough to finance the importation of water from remote sources.

The current haphazard patterns of ground-water development in all parts of the country are similar in many respects to the early stages of development of many other mineral resources. During the California gold rush, uncoordinated individual efforts, conflicting claims, and general confusion were the rule in early years, but these gave way to consolidation of interests and technically supervised operations as the gold mining became more difficult and expensive. The early development of oil fields by expensive competition among individual landowners has similarly been generally replaced by unitization and scientific extraction from petroleum reservoirs.

Water is in significant contrast to these other mineral resources in at least one respect, however. Gold and petroleum and uranium are so rare that most of us have long since given up hope of ever owning property that contains such resources in profitable amounts. But fresh water is common on the land masses of the earth. The populous regions in particular are sufficiently well watered by precipitation that men feel they have a right to it, at least enough for their reasonable needs. Unfortunately the arid and semiarid regions—which embrace most of the West—do not receive enough precipitation for the reasonable needs of agriculture or of other activities that the broad expanse of land might otherwise support. Water rights, therefore—involving the adaptation of the limited water supplies to the far more abundant land resources—have always been of major concern in Western States, and as Mr. Thomas says, they will become a real problem in any effort to achieve maximum utilization of underground storage.

Part of the water-rights problem is the lack of clear definition as to what a right right involves, or definitions that are inadequate or unworkable in the light of our present knowledge of hydrology. To give one example of many that could be cited, many well owners consider that their water right includes a right to a certain pressure head in flowing wells or to a specific static level in pumped wells, and this is supported by court decisions in some states. But by such interpretation it would be impossible to achieve full development of a ground-water reservoir for beneficial use, or to achieve a firm sustained yield in the face of varying inflow to a ground-water reservoir. On the other hand, a significant lowering of water level is likely to put a well owner to considerable expense in deepening his well or enlarging it, or in purchasing new pumping equipment. Thus society, by its increasing development of water supplies, may increase the cost of water to existing users, and thus be in conflict with the interests of those individuals.

Many water-rights difficulties arise because water rights are considered as personal property, and people commonly form a strong attachment for personal property. It might be possible for most people to drop this emotional attitude, if they could delegate the responsibility for providing an assured satisfactory supply of water at reasonable cost. This has already occurred in most metropolitan areas, for industrial, commercial, and residential users alike: Water is one of the utilities, like electricity or gas, and is furnished by a unit that specializes in water supply.

Assuming that water rights problems can be resolved in such a way as to permit scientific operation of a ground-water reservoir, an important question then will be: How much water can be withdrawn perennially from the reservoir? By analogy with a surface reservoir, the administrator of a ground-water reservoir would need basic data as to the capacity of the

reservoir (which could perhaps be broken down into the "usable" storage of fresh water within economic pumping lifts, and the "dead" storage at greater depth), the long-term average recharge to the reservoir and the annual and cyclic deviations from that average, the unavoidable losses by evapotranspiration or surface or subsurface outflow, and the effects of use upon quality of the supply. Such information is not presently available for the great majority of the nation's ground-water reservoirs. Thus in most areas a considerably enlarged basic-data program would be an essential preliminary to planned ground-water utilization.

Not all difficulties in determining the "safe" yield of individual ground-water basins can be blamed on failure to make adequate studies. In some areas we have been collecting the necessary data for several years, but we find that the climatic fluctuations are such that we cannot be certain what the "average" conditions are. As a case in point, Utah has rather detailed information for Cedar City Valley since 1935, but cannot yet be sure how much of the recorded decline in water levels in recent years is due to natural drought conditions, and how much to pumping from wells (Waite and Thomas, 1955).

One may ask what is likely to happen if development does go beyond the "safe" yield of a ground-water reservoir. Obviously if pumping continues to exceed the average rate of recharge, the inevitable result is progressive depletion of storage until the ground-water reservoir is drained; at that time, of course, pumping will be cut back by natural conditions to a rate not exceeding the recharge. There are few, if any, instances where man (either in statutes or administrative edicts or court decisions) has succeeded in cutting back the pumpage in an overdeveloped area, unless there is an alternate source of water supply available to those who are cut off (Thomas, 1955). It might happen under a dictatorship, but apparently Americans hesitate to cut off a man from the water that means his livelihood after he has actually developed and used it; they would prefer to let nature take its course.

An important element in Mr. Thomas' paper is the augmentation of the natural supplies, where necessary to meet the demand. Thus the natural inflow to ground-water reservoirs would be increased by artificial recharge, and the total water resources of deficiency areas would be increased by importation from areas of surplus. Many other states may not see any immediate need for such measures, because their ground-water reservoirs have not been developed beyond the capabilities of natural recharge; or they may not have the opportunity, because they have no areas of water surplus from which water can be transported economically to the areas of water deficiency.

Mr. Thomas points out that the usual type of public district organization covering individual ground-water basins or perhaps entire stream basins at the most, would not have the inherent authority necessary for long-distance transfer of water. However, Organization of water users on this local pattern might be a significant first step. Certainly if such units were large enough to employ specialists in water development and supply, some of the present handicaps of haphazard development by individuals might be overcome. And after such units develop the capability of rational and comprehensive development in accordance with the resource potential, it might be possible to pool their resources and transfer water in accordance with demand, on the basis of analogy with electric utilities and their pooling agreements for taking care of local surpluses and deficiencies. Presumably the development of such water utilities would require first enabling legislation,

and then increasing pressure toward greater responsibility and authority on their part, particularly in regions of greatest controversy over the water resources.

REFERENCES

Waite, H. A. and Thomas, H. E., 1955, Effects of current drought on Cedar City, Valey, Utah: Trans. Amer. Geophys. Union.

Thomas, H. E., 1955, Water Rights in areas of ground-water mining: U. S. Geol. Survey Circular 347, 16 p.

FRANK B. CLENDENEN,[1] J.M. ASCE.—Mr. Thomas has performed a valuable service to the civil engineering profession in stating clearly the value and necessity of utilization of our vast subsurface reservoirs. While the author's remarks appear to pertain to the situation and conditions in California they are just as relevant to many other areas of the United States, and to other nations where underground storage potentialities exist. There has been too great a reluctance on the part of project planners to give ground water storage utilization its proper place in their schemes. The result of this neglect has been the formulation of schemes where either surface storage has been over developed or the allocation of surface storage for non-conservation purposes has been unnecessarily reduced. The writer believes that the lack of use of ground water storage in conjunction with surface is due to the misconception that subsurface storage is not 'tried and true', that it is still too new, and that it is not reliable. This misconception should be dispelled by considering a few pertinent facts. First that without any planned operation of the ground water storage over half the irrigation water applied in California, the leading state in irrigation, is obtained from ground water storage. Second, that ground water basins such as San Fernando Valley, San Gabriel Valley, Owens Valley and Santa Clara Valley, all in California, have been successfully operated in conjunction with surface storage. Thirdly, planners for the future can quite certainly see that in the future we are either going to use our subsurface reservoirs to a large extent or many areas will be left to stagnate because of an insufficient water supply.

The author makes a plea for enabling legislation designed to accomplish state-wide (California) control of the ground water storage capacity. One of the purposes of this regulated legislation is "to provide for the imposition of general taxation in order to share the burden of costly supplies, contributing to the general prosperity of the state, among those who ordinarily secure their water supplies by other means." There is no developed water supply being used that does not contribute to the general prosperity of the state. It is sounder economics to have the principal beneficiaries of a project pay the principal cost. The danger of using "general prosperity" as justification for state tax support for regional projects is obvious.

This paper states that ".....above all, the water supply contributing to the development of the modern community must not be permitted to be subject to intersectional jealousies or political expediency." Since both of these feared deterrents of sound water supply planning already exist it appears wiser to acknowledge their existence and plan to control them than to act on

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the basis that they don't exist. It is easy to comprehend the inherent appreciation that sectional groups have for their natural resources. The reluctance of lesser developed areas to help pay for the development of their resources for the benefit of already highly developed regions is just as understandable. Recognition that any issue as important to his constituents as their water supply, present and future, demands the attention of the public servant (politician) must be acknowledged. Such important issues have historically been settled by the interested parties getting together to discuss the problem and to find a mutually agreeable solution. It is true that the water problem becomes highly complex when the conduits are hundreds of miles in length and the ground water basins underlie vast areas. It would seem that when there is need for utilization of a ground water basin that the overlying owners could be formed into a legal body and be dealt with as the owners by those desiring to exploit the storage capacity. The author has suggested a reasonable method of compensating existing basin water users for the damage that would be done them by ground water storage capacity utilization.

The basic fact that the author has expounded, that enabling legislation to allow the utilization of subsurface storage is required, is certainly recognized. Such legislation is needed soon. It is hoped that this legislation will indeed prevent 'dog in the manger' attitudes on the part of inhabitants of areas of surplus water from preventing sound water supply development and at the same time it is hoped that such legislation will not so quiet the critical individual or minority that they no longer feel their responsibility for local water resources development. It is well known that the strength of our country lies in honest, educated, responsible individuals.

It is generally concluded that ground water recharge is the key to economic conjunctive utilization of surface and subsurface reservoirs. The author states "....it is clear that the capacity of the underground reservoir to provide cyclic storage for the long-time average annual supply is solely dependent upon the rate at which such surface supplies may be placed in storage in the underground basin." This important factor in water conservation, ground water recharge, has been receiving much attention of late. Using the author's lucid illustrative example of the Tuolumne River Basin, it is seen that an artificial recharge capacity of 45,000 acre-feet per month enables conjunctive use of surface and subsurface reservoirs to develop thirty percent more water than can be developed by the surface component of the storage singly. If we use a very conservative infiltration rate of one half foot per day, the 45,000 acre-feet can be placed in subsurface storage in one month by use of only 3,000 acres, net. This is a small price to pay for the 300,000 acre-feet average annual increase in conservation. Yet it is doubtful if any spreading ponds would be required for this hypothetical operation because of the large amount of secondary or indirect artificial recharge capacity existing in the area. More attention should be directed to the tremendous amount of artificial recharge that is usually a by-product of other functions in an irrigated area.

Indirect artificial recharge of significant magnitude in the Tuolumne area is composed of irrigation, deep percolation, canal seepage, and stream seepage. For this area the amount of the applied irrigation water that percolates below the plant root zone amounts to at least one foot of water per year. Using the assumptions that the 960,000 acre-feet of irrigation water is consumptive use and that the entire service area is capable of being served surface water in a 'wet' year, the seasonal deep percolation from irrigation

amounts to about 400,000 acre-feet. As for canal seepage, the amount of water that has historically been 'lost' to canal seepage in this region is about thirty percent of gross diversion. If the total annual diversion for a 'wet' year were obtained from surface supplies and if the average irrigation efficiency were sixty five percent, the indirect recharge for a 'wet' year would amount to about 630,000 acre-feet. This annual canal seepage could be increased by operation to keep the system wet for a longer period than that required for irrigation. The monthly seepage rate of the Tuolumne River would be about 11,000 acre-feet if a percolation rate of one half foot per day and if an effective wetted stream bed area of 30 miles by 200 feet can be assumed to exist.

These three sources of indirect artificial recharge amount to an average monthly rate of 100,000 acre-feet. The variation of monthly irrigation requirement would cause the peak requirement months of the summer to have a larger recharge rate than the winter months. This rather rough estimation serves as satisfactory proof that for areas such as the Tuolumne River Basin, ample recharge capacity is available to obtain the high degree of conservation indicated by the illustrative example. The writer has made similar operation studies on the American and Merced Rivers, which along with the Tuolumne River are located in the Central Valley, and has obtained results similar to that presented in the illustrative example.

While Mr. Thomas has clearly depicted the important increase in conservation of the available supply which is creditable to the inclusion of ground water storage capacity in the scheme, attention should be drawn to the added emphasis this point requires in the light of the ever increasing cost of surface storage and the rapid increase in water demand that is being experienced now, and which will be aggravated with time.

Discussion of
"HYDRAULICS OF WELLS"

by Dean F. Peterson, Jr.
(Proc. Paper 708)

CORRECTION.—Page 708-12, Eq. 18 should read:

$$S = \frac{Q}{2\pi TG(\alpha)}$$

Discussion of "MEASUREMENT OF CANAL SEEPAGE"

by A. R. Robinson and Carl Rohwer
(Proc. Paper 728)

DEAN C. MUCKEL.[1]—The measurement of canal seepage presents problems similar to those encountered in measuring infiltration on water spreading areas for ground water replenishment. The data presented by the authors are helpful in understanding some of the factors affecting this rate—call it seepage or infiltration. Although in the case of canal seepage the desired end result will be to reduce the rate, in water spreading the aim is to increase it. In either case a thorough understanding of the factors involved will be necessary for a final solution.

The writer has made numerous measurements of infiltration on water spreading areas in California and it is noteworthy that the results obtained agree in the main with those given in the paper. The shape of the curve in figure 2 is typical of an infiltration curve over the period of time shown. A suggested explanation of the variation in rate was given in "Research in Water Spreading"[2] and is in agreement with the conclusions reached by the authors.

The use of seepage rings (commonly called infiltrometers in irrigation and water spreading studies) is widespread. However, rarely does one find different workers using the same size, depth of setting or techniques of operation. Also there is no general agreement as to the use of a buffer. Consequently, the results are not comparable and even with the same operator the results are often erratic. Standardization is needed to make the most of the data being obtained throughout the irrigated West. The seepage ring used by the authors has a disadvantage because of its large size and the amount of water required to operate it, particularly if many isolated sites are to be investigated. In water spreading investigations the writer was called upon to determine infiltration rates at locations remote from any water supply with the result that water had to be transported by truck. A much smaller unit under these conditions would have a distinct advantage over that used by the authors.

The depth of setting of a seepage ring or infiltrometer is important and a one-foot depth as used by the authors may not be sufficient in all cases to obtain the desired result. The fact that the curves for sand in figure 10 break at about 1.0 foot depth to ground water raises the question as to whether the same results would have been obtained if a different depth of setting had been used for the rings. In connection with water spreading studies[3] it

1. Irrigation Eng., USDA, Agri. Research Service, Soil and Water Conservation Research Branch.
2. Published in PROCEEDINGS ASCE vol. 77, separate 111, December 1951, by Dean C. Muckel.
3. Schiff, Leonard. The Effect of Surface Head on Infiltration Rates Based on the Performance of Ring Infiltrometers and Ponds. Transactions Am. Geophy. Union, vol. 34, no. 2. April 1953.

was found that a saturated soil column extends below the soil surface during prolonged submergence. The length of this saturated soil column will vary with permeability and depth of water on the surface. For soils with low permeability the head loss in the soil is high and the column will be short. In soils with high permeabilities the column will be longer because the head losses per unit of length are less. If the depth of setting of a seepage ring is less than the length of the saturated soil column, lateral percolation will take place while if the depth of setting is greater than the length of the soil column, no lateral percolation should occur (outside of a small capillary movement) and buffering should have no effect. It would be interesting to know if the authors performed tests with the equipment shown in figure 1 while the buffering rings were not in operation and if so what the results were.

The effect of depth to ground water on seepage rate also involves the saturated column. It is difficult to understand how ground water can affect the seepage rate unless the ground water rises to come in actual contact with the saturated soil immediately below the surface. Possibly over the range tested the soil to the water table was saturated or nearly so. A five-day period seems rather short for the time interval between changing depths to ground water. Stabilization may not have occurred on the heavier soils.

As to the effect of head on seepage rate the authors correlated seepage rate with depth of water on the soil surface. Actually the total effective head is the depth of water on the surface plus the length of the saturated soil column immediately below the surface. In terms of Darcy's equation:

$$V = K\frac{D + L}{L}$$

where D is the depth of water on the surface and L is the length of the saturated column. For the ranges in water depth used the value of L is probably small in comparison to D.

In connection with the authors' attempt to explain the effect of temperature on the basis of air entrapment it might be mentioned that in water spreading studies it was found that gases other than air were generated within a soil during a prolonged run. This was noticed particularly in laboratory experiments with soils containing quantities of organic matter and after anaerobic conditions developed. This information is not offered here as an explanation of temperature effects but merely to add another perplexity to the problem of measuring seepage over a prolonged period and to place emphasis on the difficulties involved in measuring an item affected by so many changing factors.

The authors cite the discouraging results in checking seepage meter tests with actual canal losses determined by ponding. Similar discouraging results have been obtained from experiments with small ponds, 0.005 acre in size, located within a few feet of each other on soils supposedly uniform. Rates ranging from one to several times those of adjacent ponds were obtained without apparent reason. The question is raised as to whether the authors replicated their tests at a particular site with two or more seepage rings or accepted the results from an individual seepage ring.

The authors are to be congratulated on their work in dealing with a difficult problem and the continuance of the study should be encouraged. The results will have widespread use not necessarily confined to canal seepage.

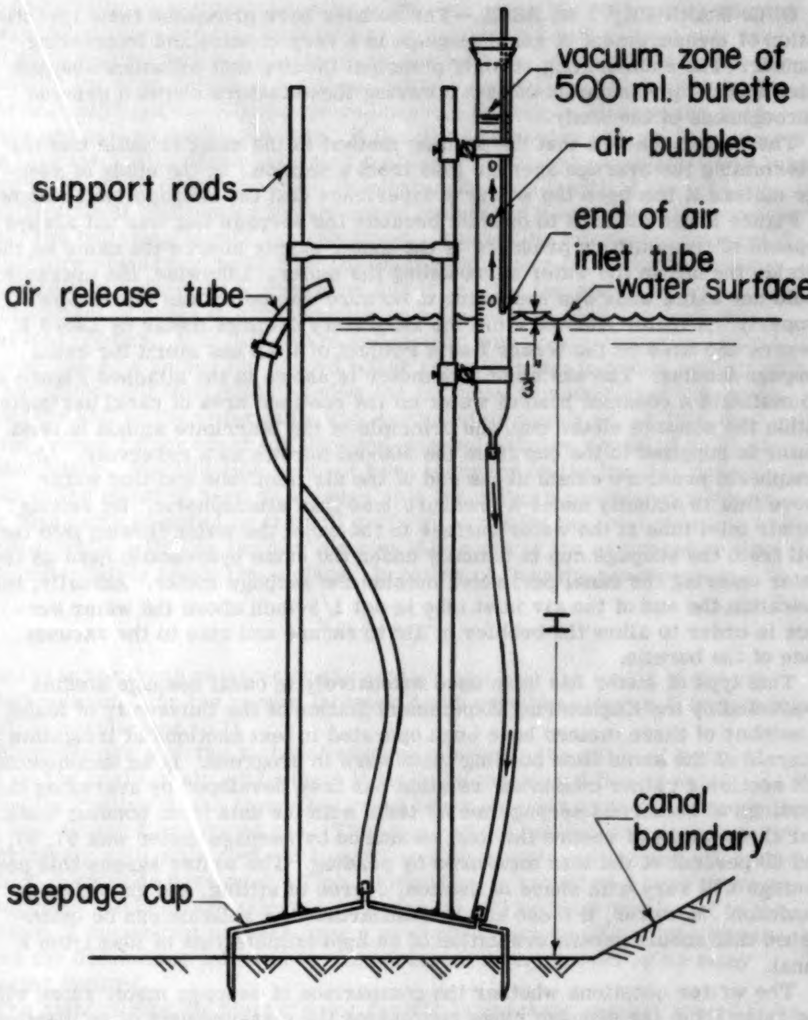
C. C. WARNICK,[1] J.M. ASCE.—The authors have presented their investigation of measurement of canal seepage in a very concise and interesting manner. The enumerating of eight principal factors that influence seepage rates and the presentation of data covering these factors shows a genuine thoroughness of the study.

The writer concurs that the ponding method is the most reliable test for determining the average seepage loss from a section. In the study of seepage meters it has been the writer's experience that the seepage meter shown in Figure 3 was difficult to operate because the seepage bag was not always capable of transmitting pressure to the meter supply source the same as that outside the bag in the water surrounding the meter. Likewise, the operator could not watch what was happening to be sure the meter was functioning properly. A meter adapted from the laboratory seepage meter by Lloyd E. Meyers and used on the Weber Basin Project of Utah has merit for canal seepage studies. The sketch of this meter is shown in the attached Figure A. To maintain a constant head of water on the confined area of canal perimeter within the seepage meter cup, the principle of the Marriotte siphon is used. Water is supplied to the cup from the 500-ml burette as a reservoir. Atmospheric pressure exists at the end of the air inlet tube and that water above this is actually under a pressure less than atmospheric. By setting the air inlet tube at the water surface in the canal the water flowing into the soil from the seepage cup is actually under the same hydrostatic head as the water entering the canal perimeter outside the seepage meter. Actually, for operation the end of the air inlet tube is set 1/3-inch above the water surface in order to allow the bubbles of air to escape and rise to the vacuum zone of the burette.

This type of meter has been used extensively in canal seepage studies conducted by the Engineering Experiment Station of the University of Idaho. A number of these meters have been operated in test sections of irrigation laterals at the same time ponding tests were in progress. In an uncompacted silt section a rather consistent relation has been developed by averaging the readings of numerous seepage meter tests with the data from ponding tests. For three years of record the loss measured by seepage meter was 57, 67, and 69 percent of the loss measured by ponding. The writer agrees this percentage will vary with shape of section, degree of silting, and groundwater condition. However, if these can be standardized, a relation can be established that should permit evaluation of an approximate rate of loss from a canal.

The writer questions whether the comparison of seepage meter rates with the rates from the seepage rings represents the measurement of an identical flow rate. It appears that the inner ring data shows the seepage rates do approach each other after a few days. Again the meter represented a localized area whereas the inner ring data represented a composite of a considerably greater area. Inserting the meter more than two or three times, it appears, would naturally change that composite figure by disturbing the soil. The fact that a seepage meter measures a localized area does represent a problem with seepage meters and because of silting in the bottom, lack of homogeneity of soil strata through which a canal perimeter cuts makes the data of a single seepage meter measurement of little real value. However, a series of careful measurements do give data on relative loss and can be of

1. Associate Research Prof., Eng. Experiment Station, Univ. of Idaho, Moscow, Idaho.



WEBER BASIN SEEPAGE METER

Fig. A

value in indicating where high loss sections are. The writer is confident that seepage meters have a place in canal seepage measurements because they represent a cheap, quick, and convenient method of measurement.

The well permeameter described in the paper presents a possible device for predicting seepage loss from proposed canals, but each test takes considerable time and again represents a very localized area. If data on loss at a localized area are used many measurements must be taken. In this respect the well permeameter does not seem to fill this need efficiently.

N. SZALAY.[1]—The measurements of canal seepage carried out by the authors show a rate of seepage decreasing with time when using seepage rings. According to the authors this decrease is due to microbiological action, the breaking down of soil aggregates and possible clogging of pores.

It must be pointed out that besides the mentioned factors, decrease of seepage rate with time is a phenomenon that has an explanation based on pure hydraulic principles too.

According to Darcy's equation, $q = K \cdot h/l$, where q is the rate of flow per unit area; K is the permeability factor; h is the hydraulic head and l is the length of the soil column. But if a canal becomes filled with water, infiltrating water fills the soil pores within a distance always increasing with time. Therefore the value of l cannot be considered as a constant, but a value increasing with time. Thus, assuming a constant head of water h, rate of flow should decrease with time because the same head is used for the overcoming of a continuously increasing frictional resistance.

As for the mathematical interpretation of the foregoing, one may be referred to the following simple application.(1) A constant head of water h should be applied on a horizontal soil surface.

The seepage velocity will be:

$$v_s = K \frac{h}{z}$$

where z = z(t) is the instantaneous depth of infiltration, as a function of time t.

The true infiltration velocity will be:

$$v_i = n \cdot v_s$$

where n is the voids ratio. The function z = z(t) can be determined from the following two equations:

$$v_i = n \cdot K \cdot \frac{h}{z} \quad \text{and} \quad v_i = dz/dt$$

By equalling the two equations and separating the variables one gets the basic differential equation for non-permanent seepage flow: $z \cdot dz = n \cdot K \cdot h \cdot dt$ and after integration:

$$z = \sqrt{2\, n\, K\, h\, t} - c$$

In order to get the rate of flow, Darcy's equation is used again:

$$q = K \frac{h}{z} = \sqrt{\frac{Kh}{2\, nt}} = \frac{c}{\sqrt{t}}$$

that is, the rate of flow is inversely proportional with the square root of time.

The accuracy of rate-of-flow measurements depends highly on the value of the infiltration area because if too small areas are taken, lateral infiltration influences much more the pure vertical infiltration than in the case of larger areas. This was proved by the experiments of L. Szabo (2) who found that under conditions above described, the measured rate of infiltration depends on infiltration area as follows:

1. Associate Prof. of Hydr. Eng., Technical Univ. of Budapest, Hungary.

Infiltration area, sq. meter	Rate of seepage
0.01	$q = C_1 \cdot t^{-0.45}$
0.02	$q = C_2 \cdot t^{-0.45}$
0.25	$q = C_3 \cdot t^{-0.46}$
16.00	$q = C_4 \cdot t^{-0.48}$
100.00	$q = C_5 \cdot t^{-0.48}$
and theoretically	$q = C \cdot t^{-0.50}$

The values of $C_1 .... C_5$ experimentally determined show a decreasing tendency with increasing infiltration area.

Finally it may be mentioned that the basic principles of the above outlined theory of non-steady seepage were also applied on pure horizontal seepage flow, as it approximately occurs by using well permeameters(1) and when infiltration develops through flood-control levees. In both cases the results theoretically computed were in good accordance with experimental data.(3)

REFERENCES

1. N. Szalay: Determination of the permeability of soil layers lying above groundwater table. Hidrológiai Közlöny, 1954./11-12

2. L. Szabo: Influence of lateral seepage upon rate-of-flow standards of surface irrigations. Hidr. Közl., 1954./7-8

3. N. Szalay: Design of flood-control levees with special regard on seepage. Hidrológiai Közlöny, 1953./3-4.

C. W. LAURITZEN.[1]—The ever increasing demand for water in arid countries has focused attention on losses in conveyance of irrigation water. One of the most perplexing problems encountered has been the accurate determination of these losses. A few methods have been employed for measuring seepage losses, but all have had their limitations and none have been entirely satisfactory. As pointed out by Robinson and Rohwer, the results obtained from ponding measurements are probably the most reliable. It might be observed, however, that ponding measurements can lead to erroneous conclusions unless antecedent conditions, as well as conditions at the time the measurement is made, are taken into consideration.

The extreme variability in seepage meter measurements made in operating canals coincides with the results obtained by the writer and his associates.[2] It has been our experience that frequently the difference between measurements made with meters set side by side is as great or greater than measurements obtained by the ponding method in canals of widely different subgrade material. The better agreement between measurements with seepage rings in uniform material would seem to indicate that part of the variability is actual. Possibly this should be expected, even though the material

1. Agri. Research Service, Logan, Utah.
2. Rasmussen, W. W. and Lauritzen, C. W., Measuring Seepage from Irrigation Canals. Jour. Amer. Soc. Agri. Eng. 34: 326-329-331 - 1951.

from all appearances is uniform. We know, for example, that stratification of the material in a soil sample can greatly alter the permeability of the material as a whole. The fact that some variability persists in the measurements made in seepage rings may indicate that there is an inherent error in the results due to installation and operation of the meters. The consistent over registration of the seepage rate, as indicated by the seepage rings, suggests the possibility of applying a correction factor to seepage meter measurements. Correction factors, based on the relation between seepage meter measurements and ponding measurements have been worked out and used by Warnick[1] in an attempt to obtain a better index of seepage losses. A correction factor based on a comparison with pending tests would, of course, take into account the difference in seepage loss between the bottom and the sides of the canal.

At first glance, such a procedure might appear to be a solution to the problem, and under certain circumstances might provide a reasonably accurate index of seepage losses. However, when we consider the fact that the relationship between the seepage from the bottom and sides of the canal may well differ widely from canal to canal and from season to season, the value of such an approach must be re-examined. Possibly a permeability measurement on disturbed samples of bed material would provide an equally accurate index of losses.

The authors point out that there are other factors besides soil type which influence seepage losses; among those mentioned is temperature. Permeability measurements are commonly corrected for temperature to take into account the change in viscosity of water with temperature. It has been the writer's experience that corrections applied to permeability measurements as mentioned by the authors give contradictory results. Apparently, some factor other than the change in viscosity of water is operating. The authors in their work seemed to have ruled out the reduction in porosity due to an increase in size of air bubbles. The fact that a correction for viscosity seems to compensate better for temperature changes with coarse-textured material than with fine indicates that the discrepancy may be associated with the fine fraction. Possibly the reduction in permeability which sometimes accompanies an increase in the temperature during a measurement can be explained by a reduction in porosity resulting from greater hydration of the clay minerals at higher temperatures. This theory, at least, might well be explored. If this should be the situation, the greater transmission of water, which would be expected to accompany an increase in temperature and the corresponding decrease in viscosity of the water would tend to be compensated for by the reduced porosity of the profile due to swelling of the constituent material.

The depth of water in the canal and the distance to the groundwater table have long been known to be important factors contributing to seepage losses. We have generally considered the increased seepage rate which accompanies an increased depth of water in the canal to be attributed to the difference in permeability of the material constituting the upper sideslopes, as compared to the lower sideslopes and bottom of the canal. Where only the bottom of a canal is taken into consideration, corresponding to measurements in seepage rings, seepage should be proportional to the hydraulic gradient, as the

1. Warnick, C. C., A Study of Canal Linings for Controlling Seepage Losses, Progress Report No. 3, Eng. Exp. Sta., Univ. of Idaho, Moscow, Idaho.

authors have shown. The problem has been to establish the value of the hydraulic gradient. It is of interest to note that as the seepage rate increases, the effect of water depth on seepage increases. It would seem that this might be explained by the steeper hydraulic gradient associated with coarse-textured material which in effect disproportionately increases water transmission as the water depth is increased. Additional information on this point would be valuable. The fact that water table depth influence was restricted to one foot for sand as compared to a greater distance for finer-textured material supports this reasoning.

It is evident from the paper that all the questions related to seepage measurement have not been solved. The investigation has, however, done much to clarify certain aspects of the problem and the authors are to be commended for their careful work and the contribution they have made.

Discussion of "RIVERBED DEGRADATION BELOW LARGE CAPACITY RESERVOIRS"

by M. Gamal Mostafa (Proc. Paper 788)

W. M. BORLAND,[1] A.M. ASCE, and C. R. MILLER,[2] J.M. ASCE.—The need for development of procedures for predicting the degradation in a stream channel resulting from a change in the natural regime is ever present in sediment engineering. Dr. Mostafa has considered the condition where clear water is released from a newly constructed storage dam. A similar problem results when a natural channel is used as a wasteway for irrigation return flows.(1) (2)

The procedure proposed by Dr. Mostafa for computing the degradation appears logical. Similar approaches have been used by the Bureau of Reclamation engineers in predicting degradation that would result from construction of Reclamation projects. Factors that control the amount of degradation are (a) size of the bed material with depth, (b) transport limit of the materials in the bed for the existing hydraulic conditions, (c) depth of bed turnover and bed armor development, (d) downstream controls, and (e) ability of the structure to retain the replenishing supply of bed material. In a completely homogeneous river channel, that is, with no downstream grade controls, no bed material variation with depth and all material transportable, the degradation will be limited only by the reduction in slope. Eventually a slope would be reached at which transport would cease. In the case where bed material is available that cannot be transported, the degradation will be limited by the depth of turnover and creation of bed armor.

In the technical analysis of the problem presented by Dr. Mostafa, the limitations of the basic data and present-day bed load formulas must be recognized. The author suggested the use of Straub's bed load formula. The writers' experience with the various formulas has shown that they are usually applicable only to the particular stream or set of conditions upon which they were derived. None of the formulas, many of which are based solely on laboratory research, can be applied with confidence to any river or condition without first establishing the applicability. The Einstein Bed-Load Function(3) and the later Modified Einstein Procedure(4) have proved to be more representative of conditions in varying types of alluvial streams in the United States. The Schoklitsch Formula(5) has been consistently reliable for computations within the medium-sand to fine-gravel size range. (0.2 mm to 8.0 mm)

Dr. Mostafa suggests that the 90 to 98 percent size as determined from the size distribution curve, is a measure of the stabilizing size. Selection of a bed material sample or samples that represent the average within

1. Head, Sedimentation Section, Hydrology Branch, Div. of Project Investigations, Bureau of Reclamation, Denver, Colo.
2. Hydr. Eng., Hydrology Branch, Div. of Project Investigations, Bureau of Reclamation, Denver, Colo.

5 percent accuracy is difficult. On Figure 1 are shown some bed material size data for the Middle Rio Grande. Note the variation from day to day and from point to point at the same cross section. The 98 percent finer size varies from 0.6 mm to 10.0 mm. Selection of the 98 percent finer size as an index to the measure of stability would not seem justifiable in most cases. Perhaps some relationship with the material, for example the 75 percent finer size, where the skew factor would not be so pronounced, would be more practical. In addition to the difficulty involved in selecting bed material that will define the 90 or 98 percent finer size, the limitations of the laboratory analysis must also be recognized. The magnitude of error increases with a decrease in quantity of material available in a particular size range.

A prerequisite to the development of procedures for predicting channel degradation must be the improvement of methods for deriving bed-material transport, obtaining representative bed material samples and size distribution, and determining the factors that result in bed armor such as depth of turnover and necessary thickness of the armor layer. Until these things are better defined the degradation based on bed load formulas will be only approximate at best.

Many times it is necessary to predict the distance downstream that the degradation will extend in addition to the depth of degradation. When two structures are involved, the aggradation-degradation balance point is the limit and can usually be established within certain limits. When no downstream control exists, the theoretical ultimate would be a bed grade parallel to the original. This never occurs because no completely homogeneous channel exists and other factors such as tributary sediment contributions retard the degradation process. The limiting factor in the case of degradation below a diversion dam is often the amount of sediment storage or ultimate trap efficiency of the dam.

Since degradation is a process of sediment transport and the sediment concentration increases with discharge, the use of mean discharge as proposed by Dr. Mostafa would not be compatible with the determination of degradation. The flow-duration curve could be used in computing the transport or in establishing a "dominant" discharge that can then be used in the degradation analysis. The "dominant" discharge can be defined as that discharge which has the most influence upon the sediment transport and the channel shape. It is readily established in a canal or a completely controlled river such as the Lower Colorado, but is difficult to establish in a river experiencing a wide range in discharges such as the Rio Grande.

Dr. Mostafa, in referring to a paper by John Stanley(6), states the closure of Imperial and Parker Dams in 1938 retarded the degradation action in the Colorado River below Hoover Dam. This suggests that the relationship in Figure 2 showing the degradation rate with respect to time would have been different if Parker Dam hadn't been built. Dr. Mostafa's reasoning in this respect is not shared for it is believed that the backwater effect of Lake Havasu (above Parker Dam) did not extend beyond the head of the Mojave Valley—that is, the gaging station located just below Davis Dam. An examination of Figure 2 indicates that the degradation rate was about 2,000,000 cubic yards per month when Parker Dam was closed in 1938. This amount is approximately one-half the maximum rate just after Hoover Dam was closed in 1935. The shape of the curve and position of the points indicate the closure of Parker Dam had no influence on the rate of degradation. Degradation below Hoover Dam was stopped by the closure of Davis Dam in

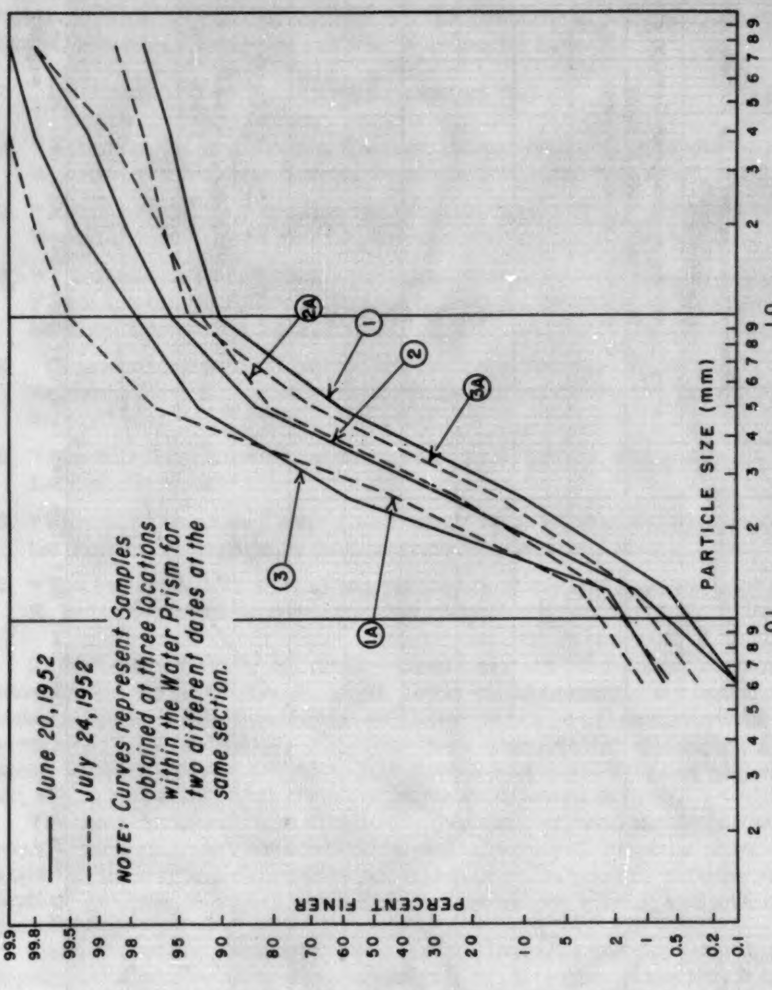


Figure 1 - Bed Material Size Analysis Curves, Middle Rio Grande River, Bernalillo Study Reach, Section F

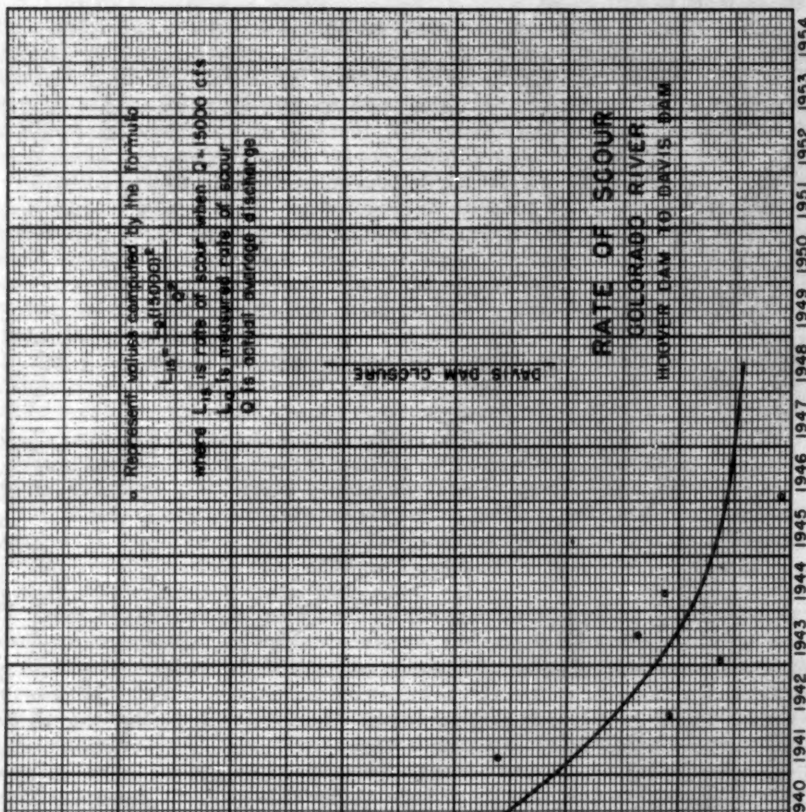

RATE OF SCOUR
COLORADO RIVER
HOOVER DAM TO DAVIS DAM
DAVIS DAM CLOSURE
PARKER DAM CLOSURE
THOUSANDS OF CUBIC YARDS PER MONTH
1937
1938
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
3000
2500
2000
1500
1000
500
250
0

FIGURE 2

1948. The rate of degradation below Hoover Dam was influenced by factors other than the construction of Parker Dam. Dr. Mostafa points out that in a purely homogeneous stream channel the degradation below a storage reservoir would proceed downstream a great distance—perhaps being governed only by the ultimate base control—the ocean.(7) The fallacy is that natural stream channels are heterogeneous—not homogeneous. Wide valleys such as the Mojave Valley near Needles, California, above Topock Forge, form areas for deposition of sediment and prevent the generalized principle, advocated by Dr. Mostafa, from being applicable to special cases.

REFERENCES

1. "A Plan of Channel Erosion Control, Fivemile Creek, Riverton Project, Wyoming," Hydrology Branch, Bureau of Reclamation report, April, 1953.
2. "A Study of Channel Erosion and Control, Muddy Creek, Riverton Project, Wyoming," Hydrology Branch, Bureau of Reclamation report, June, 1954.
3. "The Bed-Load Function for Sediment Transportation in Open Channel Flows," by H. A. Einstein, Technical Bulletin No. 1026, Soil Conservation Service, September, 1950.
4. "Computations of Total Sediment Discharge-Niobrara River near Cody, Nebraska," by B. R. Colby and C. H. Hembree, Geological Survey, Water Supply Paper 1357.
5. "The Schoklitsch Bed-Load Formula," by S. Shulits, Engineering. London, June, 1935.
6. "Effects of Dams on Channel Regimen," by J. W. Stanley, Proceedings of the Federal Inter-Agency Sedimentation Conference, 1948.
7. "The Importance of Fluvial Morphology in Hydraulic Engineering," by E. W. Lane, ASCE Separate No. 745, July, 1955.

SERGE LELIAVSKY,[1] M. ASCE.—Credit is due to Professor M. Gamal Mostafa for having produced a particularly valuable and timely paper. It belongs to the group of analytical solutions, based on parameters to be determined in the laboratory. From the more conservative standpoint, such a solution becomes an engineering fact after it was applied to, and confirmed by, say, a score or two of practical, actually executed designs.

The author's attention is directed to the fact that, with particular reference to the sediment transportation problem, a material amount of research work has been done following the inverse route, i.e. starting with the mathematical analysis of observations collected on natural rivers, and ending with the laboratory.

Since the author gives (in the Section on Discharge and Sediment Load Equations) a number of formulas referring in particular to the Nile, the writer ventures to quote another Nile-formula, which may well serve to illustrate the difference in the methods of procedure described in the last paragraph.

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1. Civ. and Hydr. Engr., Cairo, Egypt.

This formula was developed by the writer, in 1922, when in charge of the mathematical analysis of a vast scheme of observations on silt, carried out, in Egypt, on irrigation canals and the Nile.[1]

The principle embodied in this formula, namely

$$v = \left\{147 + 3{\cdot}92(z - 10)^{0.383}\right\} R^{0.85}\, S^{0.72}$$

in which v is the mean velocity in met/sec.

z " " silt in suspension in grams/met.[3]

r " " hydraulic mean depth in met.

s " " slope

10 " " minimum value of z,

was not a preconceived postulate (as is frequently the case in the modern group of similar investigations) but was a conclusion derived from an examination of these same records.

In fact, this principle was as follows: in presence of the silt the same channel is capable *ceteris paribus* of a larger discharge than that of an entirely clear water.

The formula, usually known as the *Beleida Formula*, is frequently quoted in the literature on the subject, but wrongly attributed to A. B. Buckley, in whose paper it first appeared.

At the time when it was first produced, it was possibly a too advanced solution, and met with a certain criticism as rather paradoxical.

It is therefore of particular interest to place on record that recent laboratory figures came to confirm what was originally derived 25 years earlier from a natural river. In point of fact, the well-known investigation by Professor Vito Vanoni fully confirms the principle which appeared to be a paradox when first produced.

It is tentatively suggested that the value of the paper may be enhanced, should its method be developed by explicitly introducing therein the quantitative interdependence of C and z, as yielded by this equation.

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1. Min. Proc. Institution Civil Engineers, London, Vol. CCXVI, Session 1922-23, Part ii, page 207 *et seq.*

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways (WW) divisions. Papers sponsored by the Board of Direction are identified by the symbols (BD). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper numbers are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 861 is identified as 861 (SM1) which indicates that the paper is contained in issue 1 of the Journal of the Soil Mechanics and Foundations Division.

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MARCH: 634(PO), 635(PO), 636(PO), 637(PO), 638(PO), 639(PO), 640(PO), 641(PO)c, 642(SA), 643(SA), 644(SA), 645(SA), 646(SA), 647(SA)c, 648(ST), 649(ST), 650(ST), 651(ST), 652(ST), 653(ST), 654(ST)c, 655(SA), 656(SM)c, 657(SM)c, 658(SM)c.

APRIL: 659(ST), 660(ST), 661(ST)c, 662(ST), 663(ST), 664(ST)c, 665(HY)c, 666(HY), 667(HY), 668(HY), 669(HY), 670(EM), 671(EM), 672(EM), 673(EM), 674(EM), 675(EM), 676(EM), 677(EM), 678(HY).

MAY: 679(ST), 680(ST), 681(ST), 682(ST)c, 683(ST), 684(ST), 685(SA), 686(SA), 687(SA), 688(SA), 689(SA)c, 690(EM), 691(EM), 692(EM), 693(EM), 694(EM), 695(EM), 696(PO), 697(PO), 698(SA), 699(PO)c, 700(PO), 701(ST)c.

JUNE: 702(HW), 703(HW), 704(HW)c, 705(IR), 706(IR), 707(IR), 708(IR), 709(HY)c, 710(CP), 711(CP), 712(CP), 713(CP)c, 714(HY), 715(HY), 716(HY), 717(HY), 718(SM)c, 719(HY)c, 720(AT), 721(AT), 722(SU), 723(WW), 724(WW), 725(WW), 726(WW)c, 727(WW), 728(IR), 729(IR), 730(SU)c, 731(SU).

JULY: 732(ST), 733(ST), 734(ST), 735(ST), 736(ST), 737(PO), 738(PO), 739(PO), 740(PO), 741(PO), 742(PO), 743(HY), 744(HY), 745(HY), 746(HY), 747(HY), 748(HY)c, 749(SA), 750(SA), 751(SA), 752(SA)c, 753(SM), 754(SM), 755(SM), 756(SM), 757(SM), 758(CO)c, 759(SM)c, 760(WW)c.

AUGUST: 761(BD), 762(ST), 763(ST), 764(ST), 765(ST)c, 766(CP), 767(CP), 768(CP), 769(CP), 770(CP), 771(EM), 772(EM), 773(SA), 774(EM), 775(EM), 776(EM)c, 777(AT), 778(AT), 779(SA), 780(SA), 781(SA), 782(SA)c, 783(HW), 784(HW), 785(CP), 786(ST).

SEPTEMBER: 787(PO), 788(IR), 789(HY), 790(HY), 791(HY), 792(HY), 793(HY), 794(HY)c, 795(EM), 796(EM), 797(EM), 798(EM), 799(EM)c, 800(WW), 801(WW), 802(WW), 803(WW), 804(WW), 805(WW), 806(HY), 807(PO)c, 808(IR)c.

OCTOBER: 809 (ST), 810 (HW)c, 811 (ST), 812 (ST)c, 813 (ST)c, 814(EM), 815(EM), 816(EM), 817(EM), 818(EM), 819(EM)c, 820(SA), 821(SA), 822(SA)c, 823(HW), 824(HW).

NOVEMBER: 825(ST), 826(HY), 827(ST), 828(ST), 829(ST), 830(ST), 831(ST)c, 832(CP), 833(CP), 834(CP), 835(CP)c, 836(HY), 837(HY), 838(HY), 839(HY), 840(HY), 841(HY)c.

DECEMBER: 842(SM), 843(SM)c, 844(SU), 845(SU)c, 846(SA), 847(SA), 848(SA)c, 849(ST)c, 850(ST), 851(ST), 852(ST), 853(ST), 854(CO), 855(CO), 856(CO)c, 857(SU), 858(BD), 859(BD), 860(BD).

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FEBRUARY: 879(CP1), 880(HY1), 881(HY1)c, 882(HY1), 883(HY1), 884(IR1), 885(SA1), 886(CP1), 887(SA1), 888(SA1), 889(SA1), 890(SA1), 891(SA1), 892(SA1), 893(CP1), 894(CP1), 895(PO1), 896(PO1), 897(PO1), 898(PO1), 899(PO1), 900(PO1), 901(PO1), 902(AT1)c, 903(IR1)c, 904(PO1)c, 905(SA1)c.

c. Discussion of several papers, grouped by Divisions.